Crustal velocity structure in the northern Ross Sea: From the Adare Basin onto the continental shelf

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Summary Two episodes of extension in the West Antarctic Rift System produced the Transantarctic Mountains, deep sedimentary basins in the Ross Sea, and the Adare Trough spreading center. The Adare Basin and Northern Basin are located at the northwesternmost extent of this region of deformation, and are formed in oceanic and continental crust respectively. Their boundary therefore provides an ideal study area for determining the style of extension in these two types of crust, and for understanding the continuity of deformation between portions of crust in the Ross Sea. Sonobuoy data collected during research cruise NBP0701 are processed to provide a crustal velocity structure along seismic lines trending southeast from the Adare Basin to the Northern Basin. Shallow velocities are determined using reflection data. An apparent velocity of 8100 m/s is observed in the southern Adare Basin, indicative of the mantle. This implies a crustal thickness at that location of 5.0 km, which is anomalously thin for oceanic crust. Processing of all nineteen seismic lines will provide a 3D velocity structure for the Adare Basin.

Citation: Selvans, M. M., J. M. Stock, R. W. Clayton, S. C. Cande, F. Davey (2007), Crustal velocity structure in the northern Ross Sea: From the Adare Basin onto the continental shelf, *in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES*, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 103, 4 p.

Introduction

Extension within the West Antarctic Rift System produced deep sedimentary basins in the Ross Sea (Cooper et al., 1987a) and the uplift of the Transantarctic Mountains (Fitzgerald, 1992). The expression of Cenozoic rifting between East and West Antarctica includes the Adare Trough, just east of Cape Adare in the northwestern Ross Sea, which runs into the continental shelf at its southern end (Figure 1). The Adare Basin experienced two episodes of spreading. The younger episode, from 43 to 26 Ma, is well constrained by magnetic, gravity, and bathymetric data (Cande et al., 2000a). The poorly constrained deformation during the older episode of spreading, between roughly 61 and 53 Ma, allows for up to 100 km of spreading (Cande et al., 2000b). Linking the rifting in the Adare Trough and extension in the Northern Basin to its immediate south (see Figure 1) may be achieved with further geophysical and geological studies.

The Northern Basin Eastern Edge Magnetic Anomaly is continuous from the Adare Basin to the eastern side of the Northern Basin, suggesting no offset in these structures (Cande and Stock, 2006); similarly, structural continuity is suggested by the Bouguer gravity high over the eastern Adare Basin, which extends southward into the Northern Basin (Cande and Stock, 2006). Two models for spreading in the Ross Sea are: 1) extension was taken up by stretching and thinning of continental crust such as the Northern Basin (which may require a transform fault between the Adare Basin and Northern Basin), or 2) extension was taken up by localized crustal thinning accompanied by massive intrusion into the lower continental crust. The latter is favored due to the continuity of magnetic and gravity features. A clear stratigraphy from the Adare Basin to the Northern Basin would also provide insight into the structural history of the Ross Sea, as would density constraints based on gravity data modeling.

The seismic data collected during research cruise NBP0701 address the tectonic history of the Adare Basin and Northern Basin. Refraction (sonobuoy) data are particularly useful for studying the deep crustal velocity structure, and so may clarify the distribution of oceanic and continental crust in the area. Sonobuoy studies of the Victoria Land Basin and Iselin Bank (Cooper et al., 1987b), and several other locations in the central and southern Ross Sea (Cochrane et al., 1995) revealed that the Ross Sea basins are continental material with evidence for extension. In this study, we analyze a series of continually deployed sonobuoys, obtaining deep crustal velocities along the full length of the seismic lines.

Seismic methods: Reflection and refraction

Reflection methods

Most of the multi-channel seismic data were recorded with a 1 km, 48-channel streamer and a 6-gun G/I source array with a total capacity of 20.6 liters. For the seismic lines near the continental shelf (lines 13 – 19), we used a 6-element Bolt-gun array with a total capacity 34.8 liters. The typical source spacing was approximately 40 m.

Refraction methods

Most sonobuoys transmitted data until they were approximately 25 km from the ship. For seismic lines near the continental shelf, sonobuoys were deployed such that lines overlapped (Figure 1). Refractions from the ocean-crust interface were not observed, either because the velocity change between water and shallow sediment was not large enough to refract a significant amount of energy, or because they were hidden behind earlier arrivals from deeper, faster layers. The former was often confirmed with the reflection data, which were used to determine shallow velocity structure (Figure 2).

We determined apparent velocities for deep crustal layers by applying linear-moveout (Figure 2c). The strongest reflections were often correlated with sonobuoy refractions, making the sonobuoy data useful in constructing reliable velocity profiles (Figures 2a, 2b). Overlapping sonobuoy data were particularly useful in determining the 2D velocity structure of the deep crust (Figure 3).

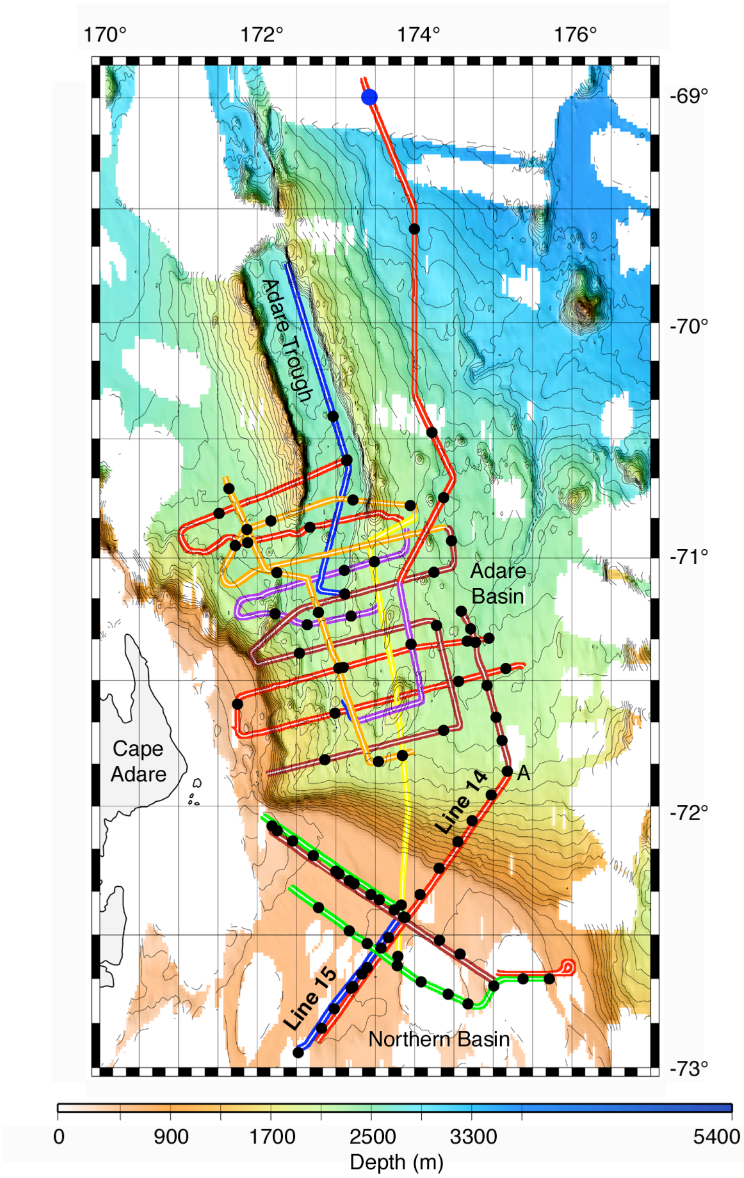

Figure 1. The nineteen seismic lines collected during NBP0701 are displayed with bathymetry of the Adare Basin region. Black dots represent sonobuoy locations; the larger blue dot at the far north is Deep Sea Drilling Program site 274. Lines 14 and 15 (labeled) are processed in this study. A velocity of 8100 m/s, indicative of the Moho, is detected at the location of sonobuoy A.

Preliminary results: Velocity structure along lines 14 and 15

Most sonobuoys deployed during the NBP0701 cruise detected multiple refractors, with apparent velocities determined by applying linear moveout, ranging from 1900 – 8100 m/s. A normal moveout applied to the reflection hyperbolae reveals apparent interval velocities of 1400 – 4000 m/s; these velocities are usually correlated with laterally extensive interfaces, as expected of sediment. Velocities greater than 2600 m/s are not observed in the reflection data in shallow water because of interference with the water bottom multiples. Linear interpolation between calculated values of velocity and depth reveals the 2D velocity structure from the southern Adare Basin onto the continental shelf of the Northern Basin (Figure 3).

With a 12-second recording interval and powerful air-gun source, we were able to detect an apparent velocity of 8100 m/s at 6.8 km below sea level, with sonobuoy A on line 14 (Figure 3). If all layers were horizontal, this would correspond to the Mohorovicic discontinuity (Moho), and implies a crustal thickness of 5.0 km in the southern Adare Basin (2.2 km of sediment, 2.8 km of basement). This would be an unusually thin oceanic crust, for which we have no explanation. Such deep, high-velocity interfaces were not detected with other sonobuoys on lines 14 and 15. On the continental shelf, the deepest refractor was at 2.5 km below sea level, with a velocity of 5000 m/s.

Of the sixteen sonobuoys deployed, seismic signals were attenuated on only three before transmission ended, indicating that in general we would detect refractors to a depth of ~5.0 km into the rock if they were present (similar to the depth of the highest-velocity refractor for sonobuoy A). Hence we infer that apparent crustal velocities are less than 5000 m/s in the Northern Basin, for depths shallower than ~5.6 km below sea level.

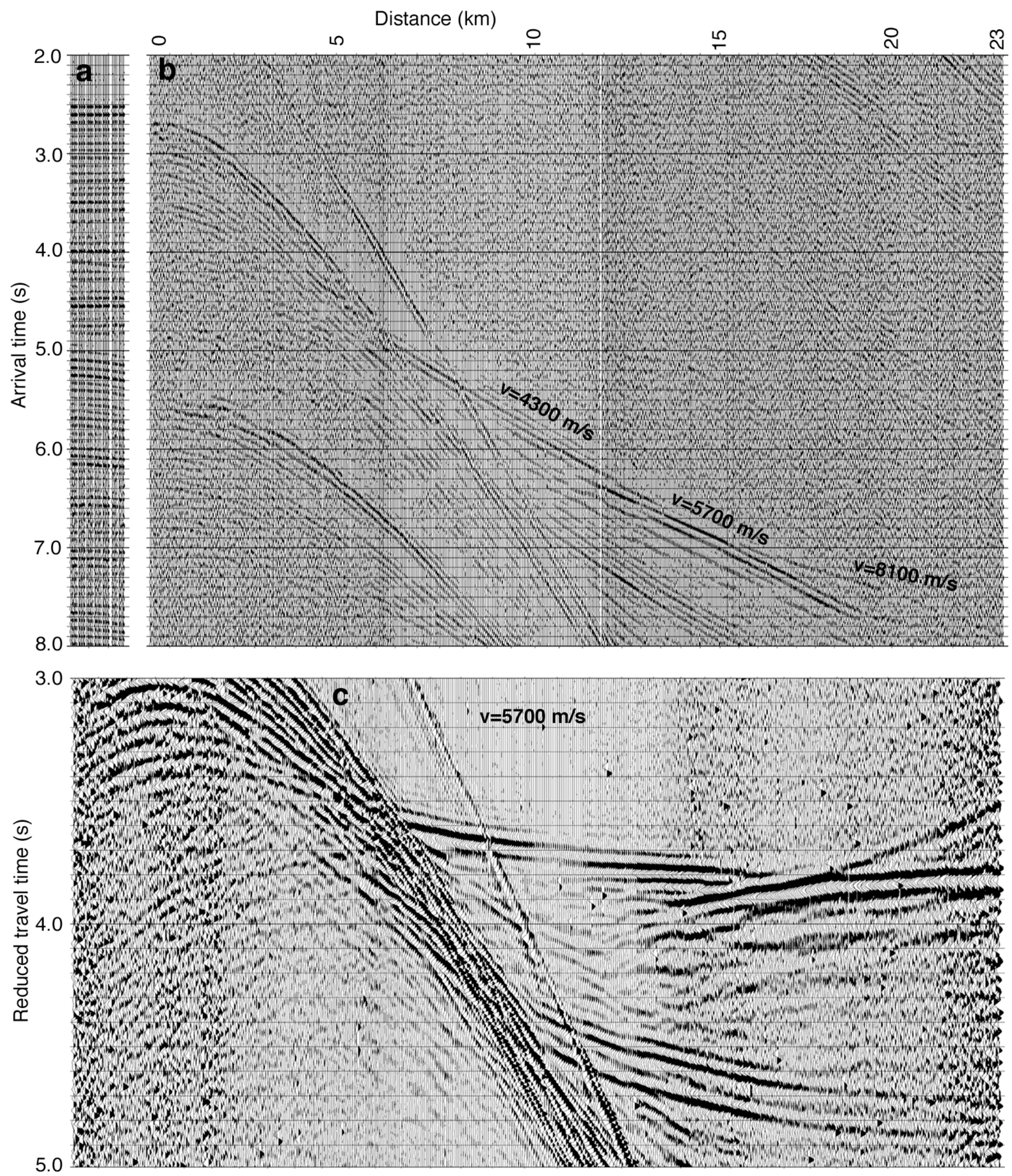

Figure 2. Strong energy returns in reflection and refraction data are often correlated, as is the case for line 14 (a) and sonobuoy A (b) in the upper panel. The deepest refractor has a velocity indicative of the mantle. An example of linear-moveout is shown for a velocity of 5700 m/s in the lower panel (c).

At the northern end of line 14, reflection data reveal laterally continuous layers to a depth of ~4.0 km below sea level, where the apparent velocity is ~5500 m/s (Figure 2). This is interpreted as the basement depth and velocity for the southern Adare Basin. On the continental shelf, the basement is not visible due to multiples from shallow reflectors that dominate the signal at depth.

Conclusions

The strong signals received by most sonobuoys until the end of data transmission imply a thicker crust for the Northern Basin than for the southern Adare Basin, but do not further constrain the thickness or velocity structure of the Northern Basin. Therefore we cannot distinguish between the two models for accommodation of extension in the Northern Basin, one predicting overall thinning and the other suggesting localized thinning and intrusion at depth. The Northern Basin is thicker than the oceanic crust to its immediate north, but may still be thinner than it was prior to the two episodes of extension in the Ross Sea. Bodies of intruded material, with relatively high crustal velocities, are not detected to ~5.0 km depth into the rock in the continental shelf, but may be present at greater depth.

However, we observe other important items in the apparent velocity structure from lines 14 and 15. A mantle interface may be detected beneath the southern Adare Basin (line 14, sonobuoy A), constraining the basement thickness to 2.8 km at that location. Lower crustal velocities cannot be constrained precisely enough to distinguish between oceanic material (~7200 m/s) and continental material (~6800 m/s).

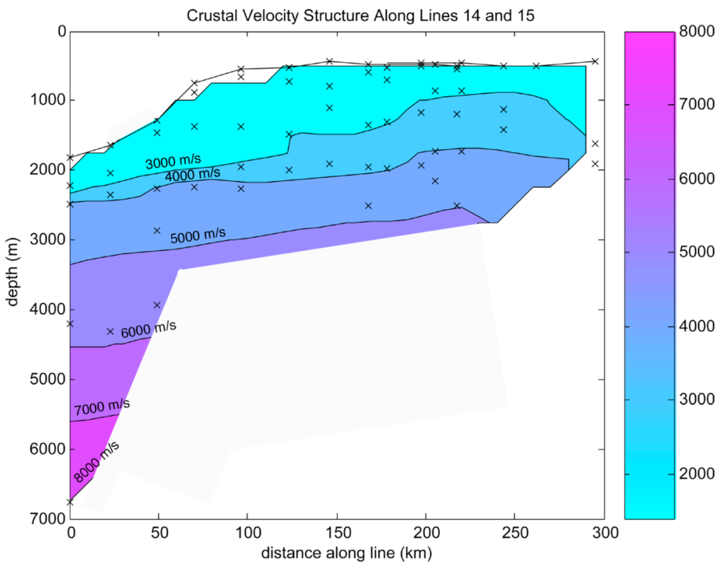

Figure 3. Crustal velocity structure along lines 14 and 15, from the Adare Basin to the Northern Basin, reveals a depth of 5.0 km to the Moho (far left). The vertical columns of x's indicate individual sonobuoys, while the x's themselves indicate interfaces in the 1D velocity models.

The lateral continuity of apparent velocity contours indicates overall structural integrity within the Northern Basin, at least along lines 14 and 15. Although we cannot detect the basement interface on the continental shelf, the lack of apparent velocities greater than 5000 m/s (assumed to apply to a rock depth of ~5.0 km) indicates a thicker crust in the Northern Basin than in the Adare Basin.

Future Work

Velocity profiles at discrete points along each line must be compared with the physical structure evident in reflection data, in order to map the layer stratigraphy from the southern Adare Basin to the Northern Basin. This will help to determine the extent of deformation in the shallow structure, which may indicate whether thinning occurred across the entire Northern Basin or was localized. Deep Sea Drilling Project (DSDP) site 274, at the northernmost end of NBP0701 seismic data collection, may constrain the layer lithologies in the study area, provided sequences can be continuously traced along the seismic lines.

The continental margin on the southern edge of the Adare Basin has several more lines of seismic data, all with continuous sonobuoy data coverage. Together, these lines will provide several intersecting 2D velocity structures. They may provide a good 3D velocity structure for this portion of the Northern Basin. Additionally, analysis of gravity data from the same ship tracks will aid in detection of lower crustal density anomalies (intrusions) if they are present, and finite difference modeling of layer densities will further test the validity of our velocity model. Velocity profiles will be determined for all 89 sonobuoys deployed during the cruise, and may be combined to produce a 3D velocity model for the entire study area. Deep velocity structure may delineate the crustal structure in the region and constrain the style of deformation during the extensional episodes in the West Antarctic Rift System.

Acknowledgements. We would like to thank Captain Mike Watson, the crew, and the Raytheon technical staff on board the *Nathaniel B. Palmer*. This study was supported by National Science Foundation grants OPP04-40959 (S. Cande) and OPP-0440923 (J. Stock and R. Clayton).

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